# Cut-Rose Production in Response to Planting Density in Two Contrasting Cultivars

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## Abstract

**Growing in lower planting density, rose plants produce more assimilates, which can be used to produce more and/or heavier flowering shoots. The effect of planting density was investigated during a period including the first five flowering flushes of a young crop. In a heated greenhouse two cut-rose cultivars were grown under bent canopy management. 'Akito' on own-roots and 'Ilios' on 'Natal Briar' rootstock were planted with densities of 8 and 4 plants per m$^2$. Starting at the end of June 2007, flowering shoots were harvested over a time span of eight months. Based on 'flowering flushes', times of high harvest rate, the harvesting time span could be divided into five consecutive periods, each including one flush. The cultivars showed contrasting responses to planting density. In the first three periods the response in 'Ilios' was extraordinary, because at low density plants did not produce more flowering shoots, as would be expected. However, the response in shoot fresh weight was larger for 'Ilios' than for 'Akito', 35% compared to 21% over the entire study period. The results imply that there was a genetic difference in the effect of assimilate availability and/or local light environment. During the first three periods, these factors can not have influenced shoot number in 'Ilios', while they did in 'Akito'. It is suggested that decreases of assimilate availability in winter caused the shoot number response to emerge for 'Ilios' later on.**

## INTRODUCTION

Planting density, the number of plants per unit of floor area, is determined by the plant configuration chosen at the time of (trans) planting. In the literature 'planting density' is frequently encountered under synonymous names like 'plant population density' and 'plant density'. In this paper 'planting density' is sometimes abbreviated to 'density'. This study deals with planting density in greenhouse cut-rose production, from the perspective of the individual plant. When grown in lower density, individual plants can intercept more photosynthetically active radiation and produce more assimilates. The additional assimilates can be used to produce a larger number of shoots and/or to produce heavier shoots. Many studies reported that rose plants respond to lower density by producing more flowering shoots (Dambre et al., 1998; de Hoog et al., 2001; Kool, 1997; Mortensen and Gislerod, 1994). Frequently the response includes an increase of shoot weight as well.

Weight is an important indicator of the quality of a flowering shoot, since it is related to the size of a shoot (Marcelis-van Acker, 1994a). Heavy shoots tend to have big flowers and high (aesthetic) value (Matthijs Beelen, pers. commun.). By growing at lower planting density, growers can enhance shoot quality at the cost of shoot quantity; although individual plants produce more shoots at lower density, the total number per square meter is lower.

Shoot production per square meter differs between cultivars. In the case of stented plants, the background of the rootstock matters as well (de Vries and Dubois, 1990; Dieleman et al., 1998; Kool and van de Pol, 1992; Nazari et al., 2009). What can also differ is the relative size of the effect of planting density on shoot number (de Hoog et al., 2001; Mortensen and Gislerod, 1994). 'Akito' on own-roots, is a cultivar known to produce a large number of shoots per square meter, while 'Ilios' on 'Natal Briar' rootstock, produces fewer shoots (Dick van der Sar, pers. commun.).

An effect of planting density is not necessarily a response to assimilate availability. The effect can also be a direct response to the local light environment, as at lower density there is less mutual shading among plants, resulting in larger quantity of local light and an altered spectrum. Both assimilate availability and local light can have a significant and substantial effects on the number of flowering shoots. Strong evidence for the effect of assimilate availability came from the positive effect of $CO_2$ enrichment on flower number (Hand and Cockshull, 1975; Zieslin et al., 1972). The effect of local light was shown with supplementary light of different spectra, with low red:far-red ratio, as encountered in canopy shade, decreasing flower number (Mor and Halevy, 1984).

Due to progress in canopy closure and seasonal differences, the effect of planting density can change over time. To see the change over time, a division of the total time span should be applied in data analysis. A division can be facilitated by 'flowering flushes'. Flowering flushes are a common pattern in a rose crop, with the harvest rate of flowering shoots typically fluctuating with a period of 5 to 10 weeks (de Hoog et al., 2000).

The objective of this study was to investigate the effect of planting density on flowering shoot production for two contrasting rose cultivars. Questions asked were: How do plants use additional assimilates obtained in a lower density? Do they produce more shoots and/or heavier shoots? Is the response different between two cultivars with contrasting productivity? Does the response change over time, in consecutive flowering flushes, after transplanting in late spring?

## MATERIALS AND METHODS

### Plant Material and Growth Conditions

The experiment was carried out in Wageningen (the Netherlands, latitude 52°N) between May 2007 and February 2008. Rose plants were grown in double rows on rockwool in a heated experimental greenhouse. From cuttings and stentlings a crop with a bent canopy was created. Two cut-rose cultivars (*Rosa* L.) were used, 'Akito' on own-roots and 'Ilios' on 'Natal Briar' rootstock. These two cultivars were selected because they could be grown in the same climate, but were expected to have different productivities. The distance between paired rows of plants was 25 cm centre to centre.

The distance between plants within the same row was 16.7 or 33.3 cm, corresponding to planting densities of 8 and 4 plants $m^{-2}$, respectively. The combination of two cultivars and two planting densities resulted in a total of four treatments. For each treatment four plots were set up as a part of a double row, including nine plants. The outer four plants were considered plot borders, leaving five neighbouring plants per plot for data collection.

Water and nutrients were supplied to the rockwool slabs via an automated drip fertigation system. The temperature set points for day and night were 20.0 and 16.5°C respectively. Ventilation or heating started when the temperature deviated by more than 1°C from the set point. $CO_2$ was supplied if the concentration dropped below 400 ppm. Supplemental lighting by high pressure sodium lamps (Hortilux Greenpower, fitted with Philips, SON-T, 600 W light bulbs) provided a minimum photosynthetic photon flux density (PPFD) of 97 µmol $m^{-2}$ $s^{-1}$ at a height of 90 cm above the rockwool slabs (above the upright canopy). At a height of 28 cm above the rockwool slabs (above the bent canopy) the PPFD was 76 µmol $m^{-2}$ $s^{-1}$ in the absence of an upright canopy. The natural day length was extended to 18 h (2:00 to 20:00), with lamps being switched on automatically when outside global radiation fell below 150 W/$m^2$. Climate and fertigation were controlled according to commercial practice.

Daily averages of temperature, relative humidity and PPFD at crop level are summarized in Table 1 for the 5 consecutive periods of the experiment (Fig. 2). Daily average $CO_2$ concentration was 400 ppm (standard deviation 14 ppm) and <4% difference between periods.

**Crop Management**

Cuttings and stentlings rooted in rockwool cubes were transplanted when they had a young primary shoot on 8 May 2007. The primary shoots were bent on 6 June, when second order lateral shoots had appeared. The first flowering shoots were harvested on 30 June. From then on flowering shoots were harvested every day. Shoots were harvested when petals had started unfurling. Blind shoots were harvested as well and dealt with as other shoots. However, blind shoots were very rare (4 out of 1378 harvested shoots), so their role is negligible.

Lateral shoots that appeared before flowering of the main stem were removed as in commercial practice, three or four times per week. Not all shoots were left growing until flowering. Some were bent down, far before flowering, to supplement and/or refresh the bent canopy. The decision to bend or to let grow was based on the location of the stem base. First and higher order lateral shoots of the bent primary shoot were bent (Fig. 1). Shoots appearing on the first 10 cm of the primary shoot outside the rockwool cube were removed at least once per week. Flower buds of the bent canopy were removed twice per week.

**Measurements**

When a shoot was harvested, harvest day was recorded and fresh weight was measured. Dry weight was measured after drying for two nights in an oven at 105°C. Plot averages were calculated for number of harvested flowering shoots per plant, mean shoot fresh weight, and cumulative harvested dry weight for each of the five periods and for the entire study period.

At the end of the experiment in February 2008, the entire bent primary shoot with all its lateral branches was cut off from all plants. Fresh weight of green leaves was measured for all plants, and leaf area for a representative set of plants (53 out of 80). Plot averages were calculated for fresh weight (g/plant), and leaf area ($m^2$/plant and $m^2/m^2$) was calculated using a linear relation between leaf fresh weight and leaf area ($R^2$=0.993).

**Experimental Design and Analysis**

Plots were arranged in a randomized block design. Each treatment was present once or twice in each of three double rows, considered as separate blocks. Data processing and statistical tests were carried out with SPSS 15.0. The effect of planting density for each cultivar was tested according to Fisher's protected LSD (least significant difference). This was a posthoc test with a linear model including cultivar and planting density combined as one factor (with four levels). In addition to a two-sided test, a one-sided test was evaluated as well. To answer the question if a quantity was larger at low density, a one-sided test is justified.

## RESULTS

Over the course of the study there was a pattern of flowering flushes marked by the alteration of high and low harvest rates (Fig. 2). The contrast in flower harvest rate was much more pronounced in 'Akito' than in 'Ilios', and flowering flushes started earlier at low planting density. Nevertheless, all treatments showed a more or less synchronous fluctuation. Based on fluctuation in harvest rate (especially of 'Akito'), the total time span could be divided into five consecutive periods which included one flowering flush. Since the time between subsequent flowering flushes increased in autumn and winter, the duration of consecutive periods became longer (Table 1).

Fluctuation in harvest rate was common to all plots, but the phase of the fluctuation was shifted: the timing of each flowering flush was slightly different. These differences were not merely due to planting density or cultivar but variability in plots of the same treatment as well. Because combining plot data would make the fluctuation less pronounced, it was preferable to represent treatments with only one plot (of the four) in Figure 2.

Cumulatively harvested dry weight (per plant) was much larger at low planting density (Table 2). This effect of density was relatively small in the first period and increased in subsequent periods. For 'Akito' the relative size of the effect increased faster than for 'Ilios'.

In period one to three, the effect on number of flowering shoots (per plant) was very different between the cultivars. For 'Akito' shoot number was larger at low planting density, while 'Ilios' was not affected by density (Table 2). After the third period, both cultivars had a larger shoot number at low density, and the relative size of the effect was similar.

Mean shoot fresh weight was larger at low planting density. However, in period one to three, the (relative) size of the effect of density was larger for 'Ilios' than for 'Akito' (Table 2). For 'Akito' the effect was not even significant in period 1 and 2.

At the end of the experiment, the leaf area of the bent canopy (per $m^2$ floor) was not significantly different between cultivars and densities ($p>0.5$, data not shown). On average there was 1.34 $m^2$ leaf area per $m^2$ floor. On a per plant basis, leaf area was about two times larger at low density.

**DISCUSSION**

The observed increase of the time between flowering flushes (Fig. 2), can be explained by the decrease in temperature and PPFD in autumn and winter (Table 1). The time of flowering shoot development of roses depends mainly on temperature (Marcelis-van Acker, 1994a; Mattson and Lieth, 2007), but the amount of daylight has been shown to matter as well (Moe and Kristoffersen, 1969). The earlier timing of flushes at low planting density could result from higher assimilate availability. Reduction of assimilate availability by leaf removal, during bud development, has been shown to increase the time between bud break and flowering (Marcelis-van Acker, 1994b).

Changes in shoot number and weight over consecutive periods (Table 2) were expected, because the young crop initially expands its leaf area develops and more branches. Additional factors could be changes in PPFD and temperature (Table 1). Amount of supplementary lighting has been shown to correlate positively with both the number of harvested flowering shoots and their weight (Bredmose, 1993). Air temperature had a negative effect on shoot weight, at least within the range of values measured in this study (Marcelis-van Acker, 1994a).

Assimilate production increases while the (bent) canopy closes. This could explain why the relative size of the effect on cumulative harvested dry weight increases over the earlier periods (Table 2). Canopy closure was still progressing at low density, while it was completed earlier at high density.

At low planting density individual plants can use additional assimilates to produce more shoots and/or to produce heavier shoots (Dambre et al., 1998; de Hoog et al., 2001; Kool, 1997; Mortensen and Gislerod, 1994). The response of 'Ilios' was unexpected, especially in periods one to three, where plants in the low density treatment did not produce more flowering shoots, only more weight, compared to plants in the high density treatment.

Lack of response to planting density implies that assimilate availability and local light environment did not affect the number of flowering shoots, in 'Ilios'. Other factors such as correlative inhibition might have been involved. After period three, assimilate availability and/or local light environment became the limiting factors, since a response to density emerged (Table 2). One factor could be decreased assimilate availability due to lower PPFD which declined substantially after periods two and three (Table 1).

The idea that assimilate availability became limiting to shoot number in 'Ilios', after period three, is supported by the observed changes in cumulative harvested dry weight and shoot number at that time: Cumulative dry weight decreased for ‘Ilios’, and it decreased by far the most at high density, approximately by one fourth (Table 2).

Assimilates not used to produce more shoots are available to produce heavier shoots. Therefore it is not surprising that the effect on shoot weight was much larger for ‘Ilios’ than for ‘Akito’ (Table 2): During periods one to three ‘Ilios’ plants in the low density treatment used the addition assimilates preferentially for increased shoot weight.

## CONCLUSION

Rose plants of the two cultivars in this study showed contrasting responses to planting density. The additional assimilates obtained at lower density were allocated in a different way. ‘Akito’ on own-roots produced both a larger number of flowering shoots and heavier shoots. ‘Ilios’ on ‘Natal Briar’ rootstock did not produce a larger number of shoots, only heavier shoots. This cultivar difference existed in the periods including the first three flowering flushes, during summer and early autumn. Later on the cultivar difference disappeared, because ‘Ilios’ plants then also produced more flowering shoots.


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## Tables

Table 1. Mean and standard deviation of the daily average of photosynthetic photon flux density (PPFD) at crop level, greenhouse air temperature (Temp.) and relative humidity (RH), in five consecutive periods of the experiment.

| Period | 1st day | Time (day) | PPFD (μmol/(m² s)) mean | PPFD st. dev. | Temp. (°C) mean | Temp. st. dev. | RH (%) mean | RH st. dev. |
|---|---|---|---|---|---|---|---|---|
| 1 | 30-jun | 33 | 172 | 20 | 23.4 | 1.8 | 69 | 4 |
| 2 | 2-aug | 39 | 160 | 21 | 22.6 | 1.6 | 71 | 4 |
| 3 | 10-sep | 48 | 122 | 19 | 20.1 | 0.7 | 73 | 4 |
| 4 | 28-okt | 59 | 86 | 8 | 18.3 | 0.6 | 77 | 3 |
| 5 | 26-dec | 60 | 88 | 11 | 18.5 | 0.6 | 76 | 3 |

Table 2. Number of harvested flowering shoots, mean shoot fresh weight, and cumulative harvested dry weight of the flowering shoots for five consecutive periods of the experiment (see Table 1 and Fig. 2). For each cultivar, the relative size and the significance of the effect of planting density (P. density) are given. ‘Rel. dif.’ is the relative difference of low density (4 $m^{-2}$) compared to high density (8 $m^{-2}$).

| Cultivar: | 'Akito' on own-roots | | | | 'Ilios' on 'Natal Briar' rootstock | | | |
|---|---|---|---|---|---|---|---|---|
| P. density ($m^{-2}$): | 8 | 4 | | | 8 | 4 | | |
| Period | | | Rel. dif. | Sig. | | | Rel. dif. | Sig. |
| *Number of harvested flowering shoots* | | | | | *(per plant)* | | | |
| 1 | 1.95 | 2.55 | 31% | s1 | 2.30 | 2.05 | -11% | ns |
| 2 | 2.65 | 3.90 | 47% | *** | 2.80 | 2.65 | -5% | ns |
| 3 | 3.50 | 5.15 | 47% | *** | 3.40 | 3.15 | -7% | ns |
| 4 | 4.15 | 5.75 | 39% | ** | 2.60 | 3.60 | 38% | * |
| 5 | 3.90 | 5.45 | 40% | * | 2.60 | 3.65 | 40% | s1 |
| 1-5 | 16.2 | 22.8 | 41% | *** | 13.7 | 15.1 | 10% | ns |
| *Mean shoot fresh weight* | | | | | *(g)* | | | |
| 1 | 42.6 | 47.4 | 11% | ns | 44.5 | 57.2 | 28% | ** |
| 2 | 41.0 | 45.7 | 11% | ns | 45.6 | 65.9 | 45% | *** |
| 3 | 40.2 | 49.0 | 22% | ** | 48.2 | 72.8 | 51% | *** |
| 4 | 35.6 | 46.9 | 32% | ** | 45.9 | 60.4 | 32% | *** |
| 5 | 39.1 | 49.0 | 25% | s1 | 45.5 | 56.4 | 24% | * |
| 1-5 | 39.0 | 47.4 | 21% | *** | 46.2 | 62.2 | 35% | *** |
| *Cumulative harvested dry weight* | | | | | *(g per plant)* | | | |
| 1 | 18.2 | 26.7 | 47% | ** | 25.3 | 30.7 | 21% | * |
| 2 | 23.7 | 38.7 | 63% | ** | 31.7 | 45.7 | 44% | ** |
| 3 | 30.6 | 57.2 | 87% | *** | 40.7 | 58.7 | 44% | ** |
| 4 | 32.6 | 59.3 | 82% | ** | 30.3 | 56.3 | 86% | ** |
| 5 | 34.7 | 59.8 | 72% | ** | 31.0 | 53.8 | 73% | ** |
| 1-5 | 140 | 242 | 73% | *** | 159 | 245 | 54% | *** |

*, **, ***: The effect was significant at 0.05, 0.01, 0.001 in a two-sided test.

s1: The effect was significant at 0.05 in a one-sided test (Was it larger at low density?), but not in a two-sided test.

ns: The effect was not significant at 0.05 in any test.

**Figures**

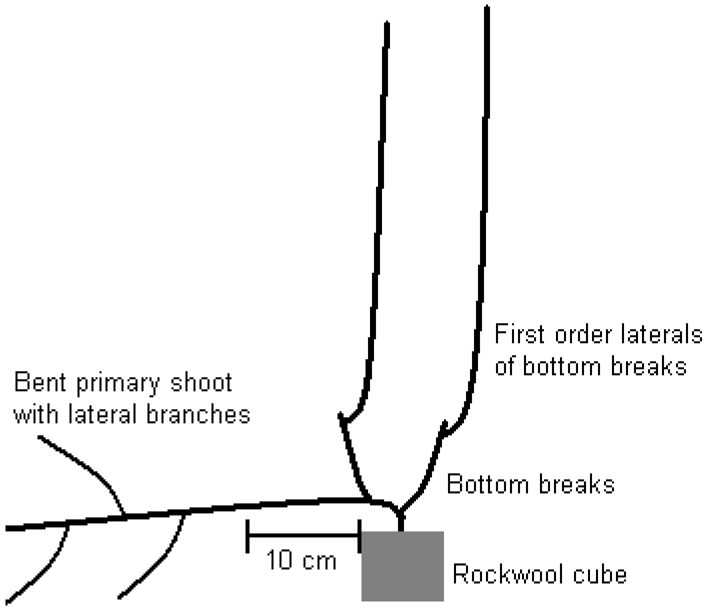


Fig. 1. Plant architecture in relation to crop management. The bar with '10 cm' indicates the part of the primary shoot, that was kept free of lateral shoots. See 'Methods' for explanation on the crop management.

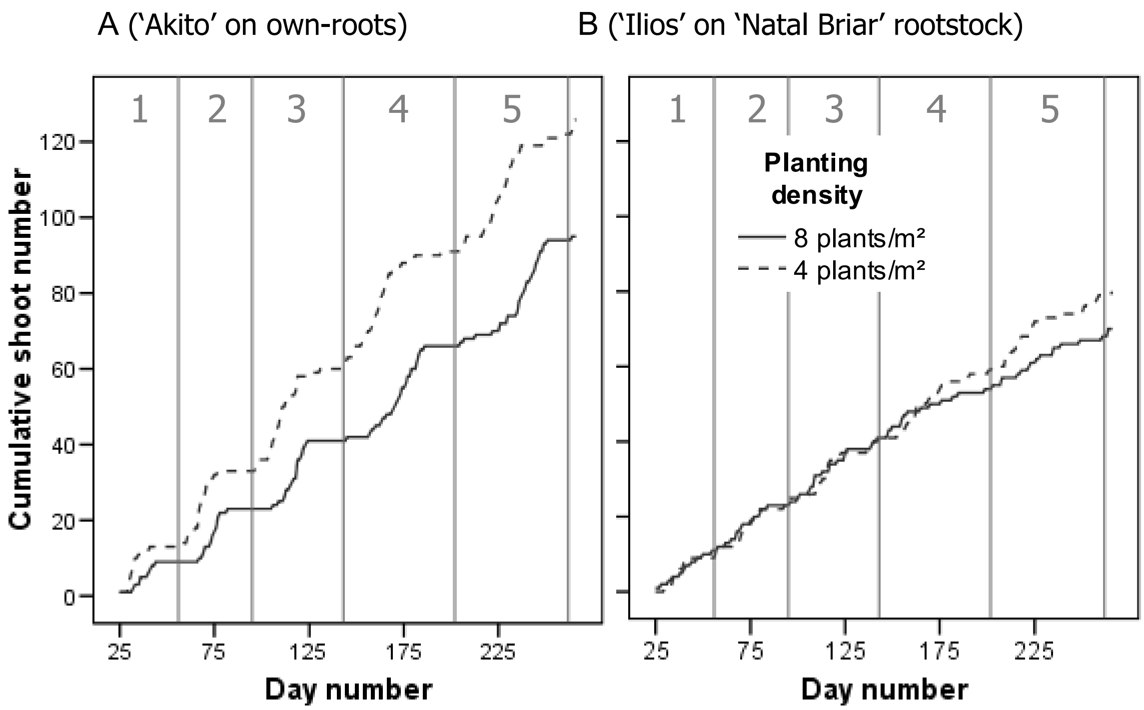


Fig. 2. Cumulative number of harvested shoots over time. Day 0 is the day of bending the primary shoots, 6 June 2007. Each treatment is represented by a single plot only (one of the four). The vertical lines display the division of the harvesting time span into five periods (1-5). The division was derived from the fluctuating harvest pattern of 'Akito'. Each period contains one flowering flush.